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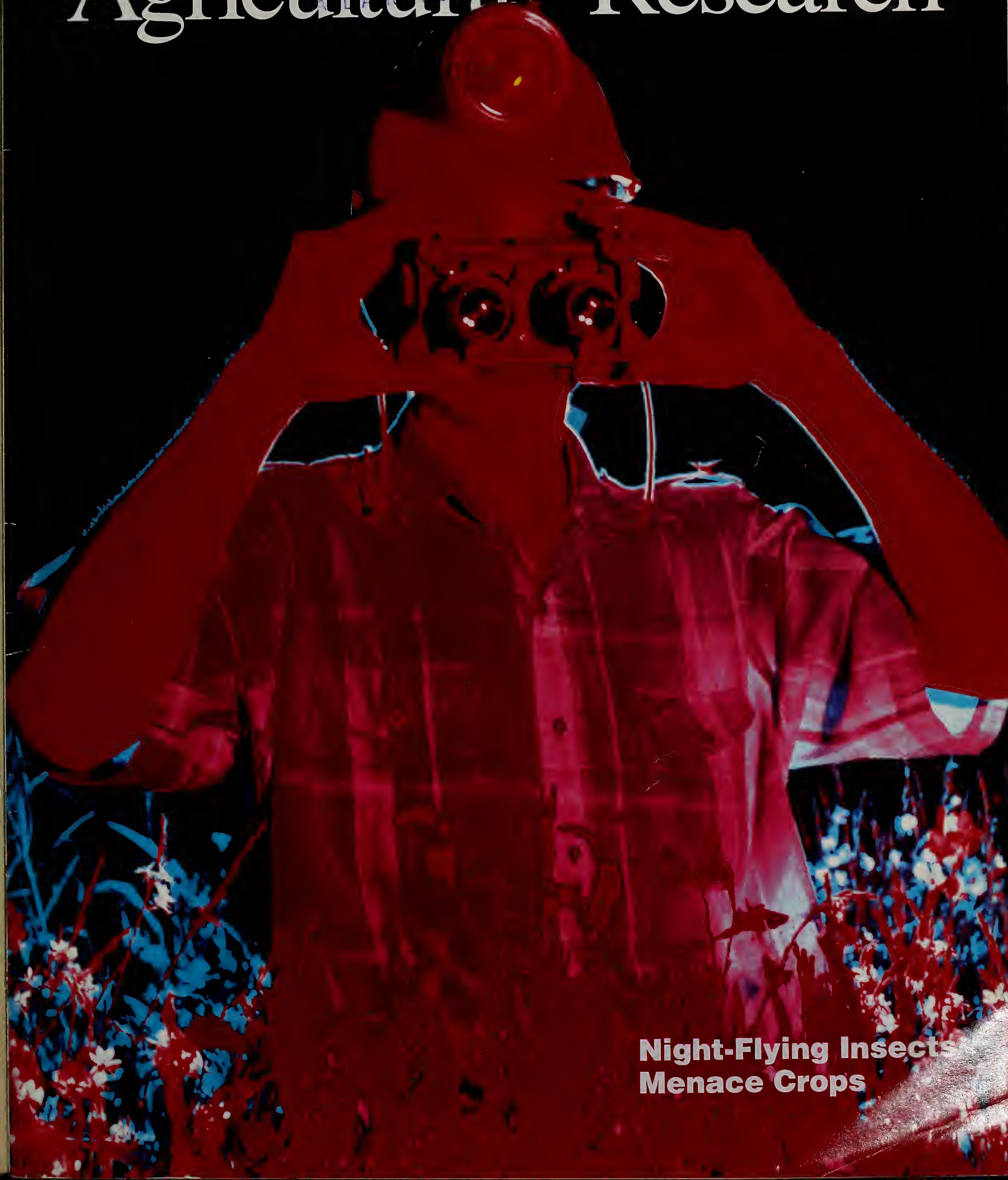
…epartment of Agriculture Agricultural Research Service December 1994

Agricultural Research



Night-Flying Insects Menace Crops

FORUM

Taking an Areawide Offensive

In the modern struggle against destructive crop pests, our traditional strategy has been a defensive one: Expect to lose some of the battles, as long as we ultimately win the war.

At the farm level, we've focused on economic thresholds, calculating how much of the crop we can afford to give up to the pests, balanced against potential environmental harm or cost of available control measures.

Now there's a new battle plan—areawide pest management.

This is really a dual concept. First, as the name implies, its success relies on areawide participation and cooperation by agricultural producers. There's little value in treating farmer Jones' fields against cotton bollworm when the pests can simply cross the fence to farmer Smith's fields to proliferate.

Second, areawide pest management isn't defensive; it ends that waiting cycle. It's active, going on the offense against the destructive pests, gathering and using data to understand where they originate, how they move, when and where they're most likely to attack. It gives the agricultural community a chance to strike the first blow.

In 1987, entomologist Alton N. Sparks was research leader of the ARS Insect Migration Research Team at Tifton, Georgia. Sparks, now retired, wrote in an *Agricultural Research* Forum that "Pilot programs may be the only way to determine the wisdom of areawide offensives. Such programs, if undertaken, must approximate the conditions that would occur areawide."

Today the types of pilot programs that Sparks envisioned are a reality. This year, ARS began leading a pilot study on the areawide management of codling moth on apples and pears using mating disruption as the key technology for management. ARS also began the planning phase of a pilot study on areawide management of corn rootworm using an attracticide system; we hope to put that study into action in October 1995.

If these and future similar pilots are successful, they offer us a tremendous opportunity to reduce environmental risks from pesticides, as well as to increase effectiveness of integrated pest management (IPM) systems—a strategic deployment of all the pest-fighting weapons at our disposal—and increase the crop acreage under IPM.

Although areawide pest management has clearly been given support and encouragement by the current administration, the concept embodied in this approach to IPM has been supported by leaders in entomological research for many years.

A classic example is the groundbreaking work by retired ARS entomologists Edward F. Knipling, Raymond C. Bushland, and others in designing and implementing eradication of the screwworm in the United States. Their approach relied on irradiation of males to render them sterile, then loosing them to mate ineffectively with the native females.

If this had been attempted on a ranch-by-ranch basis, it would not only have failed miserably, but probably would have been labeled a "harebrained idea." Instead, by implementing the eradication effort over a wide geographic area, the program was highly successful and has been credited by some with the salvation of the livestock industry in the southwestern United States.

When Alton Sparks wrote in 1987 about areawide pest management, he noted that for such a system to work, entomological data on insect movement were vital. Unfortunately, in 1987, such data were also speculative and circumstantial.

Today our knowledge of insect migration is considerably more concrete, and we are building on it constantly through studies such as those under way at our Areawide Pest Management Research Unit at College Station, Texas. We know much more about how insects travel on the winds and how their movements are affected by weather; we're learning about tracking them to their source based on their feeding habits.

And that's good news for farmers, the environment, and consumers, too, who will reap the benefits of area wide pest management through healthier, more plentiful products from American agriculture.

James R. Coppedge
Areawide Pest Management Research Unit
College Station, Texas

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Cover: Understanding moth behavior is essential to applying effective control methods against mobile pests. Here, technician Jesus Esquivel uses night vision goggles and infrared lighting to watch corn earworm moths that have emerged from cornfields (behind him) to feed on nectar of night-blooming plants, such as gaura. Photo by Jack Dykinga. (K5694-19)

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Vol. 42, No. 12
December 1994

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The Secretary of Agriculture has determined that publication of this periodical is necessary in the transaction of public business required by law.

Agricultural Research is published monthly by the Agricultural Research Service, U.S. Department of Agriculture, Washington, DC 20250-2350.

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Subscription requests should be placed with New Orders, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954. Please see back cover for order form.

This publication was printed with soybean oil-based ink. When writing to request address changes or deletions, please include a recent address label. Address magazine inquiries or comments to: The Editor, Information Staff, Room 408, 6303 Ivy Lane, Greenbelt, MD 20770

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Hit 'Em With All We've Got

They call their forays field campaigns.

When the signal comes up from the valley that the enemy is on the move, Peter D. Lingren and his colleagues are ready. They move in with computer-equipped vans, radar, weather balloons, and aircraft to track the invaders and gather intelligence about their strength and capabilities, in hopes of someday thwarting them and sounding a timely alarm to potential victims farther north.

Lingren's team is constantly on the lookout for bugs, but not the type used in espionage: They're waging war in Texas against *Helicoverpa zea*, alias the corn earworm, cotton bollworm, or tomato fruitworm.

"In the United States, losses from damage and control of *Helicoverpa* species total at least $1.5 billion a year," says Lingren, an entomologist in the ARS Areawide Pest Management Research Unit at College Station, Texas.

"And it's not just corn and cotton that the earworm goes after," he continues. "It also causes annual losses of more than $125 million to U.S. horticultural crops."

Like the team members on the old television program "Mission: Impossible," each member of Lingren's group is a specialist. At the College Station lab, chemist Ted N. Shaver searches for just the right aroma to tempt corn earworm moths to a deadly feast, while Kenneth R. Beerwinkle uses his engineering expertise to test the appeal of natural chemicals.

Entomologist Juan D. Lopez, Jr., is probing how the insects choose their food. Agricultural engineer Wayne W. Wolf takes to the air to track how insects move in flight, and meteorologist John K. Westbrook explores the ways weather affects those movements.

Down in Weslaco, Texas, entomologist Jimmy R. Raulston shares his knowledge of how the pest population develops in an area over time and when it's likely to move.

Back at College Station, ARS' Gretchen D. Jones works with Texas A&M University's Vaughn M. Bryant, Jr., to study pollen grains on the moths as clues to where the pests have been and what they ate, while ARS entomologist Jesus F. Esquivel concentrates on adult feeding behavior on citrus.

JACK DYKINGA

Agricultural engineer Ken Beerwinkle watches responses of hungry corn earworm moths exposed to different plant odors in a six-choice olfactometer. Olfactometer bioassays are used to identify the specific chemicals that attract moths to feed on plant nectars. (K5699-1)

More than 30 years have passed since Pete Lingren first dreamed of an integrated push against the corn earworm that would consider everything from the insect's tastes in food to its capacity for flight. But it wasn't until 1987 that he was able to begin the current project.

That year Lingren wrote a research plan centered on a simple idea: develop an attractant to entice adult earworm moths of both sexes to eat a control agent, such as a pesticide, at the best place and time for efficient control.

The next spring saw Lingren and his coworkers spying on the pests' nighttime behavior in cornfields. The scientists watched earworm moths spiral upward from the fields in the early dusk. Then they'd trail the pests downwind as far as possible on four-wheelers.

"We used night-vision equipment and other techniques to determine how fast the insects rose, which direction they were going, and how fast they were flying," Lingren says. "We also put traps downwind from where the insects emerged, to see how far away we could catch them."

It's a Long, Long Trail

For Lingren's research team, the trail of the corn earworm often begins at Weslaco, where Jimmy Raulston has spent more than a decade studying how corn earworm populations grow and spread from the lower Rio Grande Valley's half million acres of corn and accommodating early spring warmth. Raulston heads the ARS Subtropical Cotton Insects Research Unit at Weslaco.

Adult earworm moths lay their eggs directly on the silk of the growing corn, where the larvae hatch about 3 days later. Over the next 2 weeks, the newly hatched larvae eat their way through the silk and many kernels, then cut out of the husk, to drop to the soil and burrow in. After about a dozen days, new adults emerge from the soil, pump their wings, and fly away in search of fresh food.

"A typical year would see 4 or 5 billion insects emerge from this area,

although we did estimate as many as 7 billion for 1985," recalls Raulston. "By the time that new generation of adults emerges from the soil, the field is no longer attractive to them because the corn is maturing. So the insects disperse."

When Raulston perceives a major emergence is imminent, he alerts Lingren's unit to move in. One team member who definitely doesn't travel light is Wayne Wolf, whose baggage includes three types of radar and an airplane. Wolf, who has been using radar to track insects for ARS since 1978, joined the College Station team in 1991. "We have two scanning ground-based radar units and also an airborne radar that we use to follow the cloud of insects," he says.

Up and Away

The moths' favored time for departure is about 30 minutes after dusk, when they can rise at a rate of 3 to 6 feet per second and cruise at heights up to 5,000 feet. As the ground-based radar confirms the ascent of the insect cloud, Wolf uses radar in a small plane to scout the outer edges of the mass.

"I follow the cloud until the insect density isn't there anymore on the radar," he explains. "The airborne radar gives us a way of comparing actual dispersal of the insects with where we predicted they'd go."

Meanwhile, back on the ground, one radar unit monitors passage of insects through a vertical beam, while another unit downwind of the insects' takeoff point indicates the pests' behavior after a certain number of miles of flight.

Unlike the insects, Wayne Wolf can't keep flying all night; the project's budget won't allow it. Instead, after he's scouted out the insect cloud's far edges, he lands and waits a few hours, then takes off

JACK DYKINGA

Readying for nighttime surveillance of migrating moths, agricultural engineer Wayne Wolf (left) adjusts a radar dish. When initial moth flight is detected, meteorologist Ritchie Eyster will launch a constant-altitude tetroon. Its movement will be tracked by Argos satellites and a mobile LORAN system to measure winds that affect moth mobility. (K5698-1)

again to find and measure the density of the cloud. Knowing where to look is made easier by information from John Westbrook and his ruby-red tetroons—enormous plastic weather balloons shaped like inverted pyramids.

"These balloons help us get information on wind, temperature, and humidity along the insects' approximate flight path," explains Westbrook. "We synchronize the launch of a tetroon with the insects' movement, en masse, from the source area. We ballast the balloon so it drifts at the same altitude as a high concentration of the insects. The balloon's movement gives us an idea

of where the insects might have flown during the night so we can deploy our personnel and equipment more appropriately."

As the balloon meanders through the night, Westbrook and co-workers follow as closely as possible in a van loaded with a computer and tracking system. The van's system collects atmospheric data from a transponder strapped to the balloon. Shortly before sunrise, an electronic alarm clock on board the balloon sets off a small charge that melts a hole in the balloon, sending it drifting earthward so the scientists can recover and reuse the costly transponders.

"One of our assumptions at this point is that the wind drift approximates the direction and distance the insects are moving," Westbrook notes. "When we find out insect movement from trapping or other means, we can compare that with our balloon measurements. We know the balloon is not actually marking the path of the active insects, but it's staying near their airspace."

Wind information is vital, because upper air currents provide a natural shuttle system for the migrating pests, Westbrook says. "Insects could be moved by the wind 250 to 300 miles a night. The tetroons allow us to measure atmospheric activity where the insects are doing their thing."

Like Wolf and Westbrook, Juan Lopez works at night, but his base of operations is at College Station.

JACK DYKINGA

This corn earworm moth's response to a sugar solution will help entomologist Juan Lopez develop feeding attractants to be incorporated into a moth attracticide. (K5702-1)

Below right: Sensors on the moth's unrolled proboscis will tell it whether this solution is suitable for feeding. (K5701-1)

We know adult moths need food to lay eggs and fly, and we also know a major source of that food is plant nectar," Lopez explains. "I'm studying the composition of nectar and how it influences feeding behavior."

Pinpointing the pests' food preferences is vital to developing an appealing synthetic alternative that could be laced with the extra wallop of pesticide, Lopez says.

"Anything we put out in the field to attract these insects must compete with their natural sources of food," he points out. "So we must know what those natural sources are."

When a corn earworm moth finds a tasty treat, it begins to feed by extending a long tube, the proboscis, that is normally coiled against its head. "It's a reaction a lot like your mouth watering," says Lopez. "Something very specific triggers that extension."

The key may be chemical receptors on the insect's legs and antennae. Lopez has experimented with exposing these chemical receptors to 10 sugars and has seen a positive response—the unrolled proboscis—to four of them.

"They're very responsive to honey and to the nectar of gaura, a night-blooming plant found in Texas," says Lopez. "I think the key is sucrose content; these moths definitely have a sweet tooth. But it's not solely a matter of sweetness, because they didn't like saccharin or aspartame."

The "taste tests" give Lopez lots of hands-on experience with the moths—literally. Sugars are placed on plates and scientists hold the moths by their wings over the plates to allow their legs to touch the sugars.

"We use a similar procedure to test for response to flowers of different plants," Lopez says. "We've found responses to gaura, bitterweed, dallisgrass that's infected with a fungus called ergot, and a species of willow."

An unrolled proboscis is no guarantee the moth will feed, Lopez adds. "There are additional sensors on the proboscis that determine whether to feed or not. But we've found the insect will salivate, to

JACK DYKINGA

dilute what it's feeding on and make the material easier to take up. This is important because it means they'll eat dry material, which gives us more leeway in formulations we might put out in the field."

Volatile Attractants

Before the moth eats anything—be it a product of nature or laboratory—it has to first be attracted. As surely as firing up the backyard barbecue tantalizes the neighbors, corn earworm moths are drawn to plants by scents of volatile chemicals. College Station's Shaver and Beerwinkle are working to identify and mimic the moths' favorite aromas.

Shaver collects volatiles both from plant blooms that have been picked and from intact flowering plants placed in a bell jar. As air is passed over the flowers, it picks up volatiles that are then captured on adsorbent material for later extraction.

"The advantage of this technique is that we're obtaining chemicals as they are emitted from the flower," Shaver says. "This is closer to what the insect is detecting in the fields."

Shaver and Beerwinkle have worked with volatiles from three gaura species, two oak species, and two willow species, as well as from grapefruit, orange, and a handful of weeds, including bloodweed, dallisgrass, and goldenrod. "Coworkers have observed the insects feeding on all these plants at night or have found pollen from them clinging to the insects," Shaver says.

"We're now trying to find chemicals in these volatiles that are common to the different plants," he continues. "We've found two that are common to eight species, one chemical in seven species, a couple of chemicals in six species, and several in five species."

"There may be more than 100 volatile compounds in an individual plant," Beerwinkle adds. "We have to find the two or three that are actual attractants. For example, goldenrod had 30 compounds identified; we have to find the key elements and also how the plant releases the mixture. So far, we've tried up to 100 combinations of chemicals but haven't found anything the insect likes as well as the plant's natural product."

To test the appeal of various volatiles, Beerwinkle and coworkers developed a device called an olfactometer. Chemical mixtures are put on cotton rolls inside tunnels within a Plexiglas chamber. Up to 100 hungry moths are turned loose in the chamber and air is blown in, tempting the moths with the various scents. A chemical is deemed a hit when moths follow the tunnel to that mixture's cotton roll.

"We feel like we're getting closer," Beerwinkle says. "We have some compounds now that have definitely shown attractance. But we hope to find something so appealing that the moths will be drawn to it, instead of to what's naturally present in the field."

Following Pollen Trails

Even as Shaver and Beerwinkle struggle to find just the right scent to tempt tomorrow's moth to a deadly treat, Gretchen Jones, Vaughn

JACK DYKINGA

Scanning electron microscopy analyses provide helpful insights into insect mobility. Here, entomologist Pete Lingren (right), biologist/palynologist Gretchen Jones, and Texas A&M professor Vaughn Bryant discuss high-magnification photos of pollen grains found on corn earworm moths. (K5703-1)

Bryant, and Jesus Esquivel are trying to pinpoint where the moths fed yesterday by studying pollen on the pests' bodies—a science called palynology.

"These insects are nectar feeders. So if they get pollen from a plant on their bodies as they feed, identifying the pollen should be an easy way to find their food sources," explains Jones. "The problem is: There are a lot of flowering plants, and each species makes its own distinctive-looking pollen grain."

In fact, pollen identification is anything but simple. For starters, "Some of these moths are pretty big, and they might have only two or three pollen grains on them," says Bryant, director of Texas A&M's Palynology Laboratory. "And we're using scanning electron microscopy (SEM), which is time-consuming and expensive. It can take almost an hour to effectively look at just one moth's head."

Identification is further complicated because certain pollen grains' most striking characteristic may appear only at one spot on the grain. If the grain lands "facedown" on the insect, that characteristic is hidden.

"Probably 40 percent of the grains you find can't be identified because their key characteristic isn't in view, but there's no effective way to pull the microscopic pollen off the insect and study it," says Bryant.

Another problem is that most pictorial guides to pollen were done with a compound light microscope with limited depth of field, so each view usually depicts only a thin slice of the grain, showing parts of its exterior and interior structures. SEM's, however, show the pollen grain's whole exterior in a single view.

"It's like looking at a kiwi fruit, slice by slice, compared to looking at the whole fruit," Jones says. "Trying to identify these pollen grains with the existing guides was a nightmare."

Since the materials at hand weren't much help, Bryant, Jones, and Lingren have been compiling their own picture atlas of pollen SEM's over the past 4 years. "It identifies the pollen types of 440 species of plants that grow in the southern United States and shows them as SEM's," Bryant says. "That's helpful for this project. But if this atlas is to be used by other researchers in other studies, 440 species out of the 300,000-plus types is just a drop in the bucket."

While the scientists are understandably proud of their continually expanding pollen atlas, it is only a sidelight to the original aim of the corn earworm migration work with Lingren.

"In the spring, these moths travel by the millions to other corn-growing areas," Jones explains. "The question is, where are they coming from? By tracking pollen types, we can determine that they've been feeding on specific plants in specific areas. The pollen tells us that they came from a location with a particular type of plant, and we can put that together with weather information to determine where they might have migrated from."

At the center of all this activity is Pete Lingren, a man with a simple idea: Find what the adults like to eat, then offer a deadly artificial substitute before they begin to spread.

"We want to develop an areawide management strategy so that when the moths come out in the spring, they never make it to the next climatic zone," Lingren concludes. "It's a matter of stopping the problem at its source. If you kill one female adult, you've eliminated the potential for 1,000 progeny."—By **Sandy Miller Hays,** ARS.

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Not Just for the Holidays

In the 1930's, Americans consumed about 23 pounds of sweetpotatoes per person each year. Last year, per capita consumption hit an all-time low of 3.9 pounds.

Loaded with beta carotene and only a trace of fat, sweetpotatoes—even candied—have fewer calories than a spinach soufflé. They have been an important food source since ancient times. But, in the United States, sweetpotatoes have been declining in popularity for many years.

Why would a food that is good tasting and so obviously good for you fall out of favor?

"Most people unfortunately think of sweetpotatoes as a seasonal food, to be enjoyed around the fall and winter holidays," says Gary Lucier, an economist with USDA's Economic Research Service. "The trend also seems to be that sweetpotatoes are more popular with older people in the South. We need to get all age groups in all geographic areas interested in this nutritious vegetable."

In the 1930's, Americans consumed about 23 pounds of sweetpotatoes per person each year. Lucier says that last year's per capita consumption hit an all-time low of 3.9 pounds.

William M. Walter, an ARS chemist, hopes to reverse the trend with the help of North Carolina State University scientists Van-Den Truong and Karina Sylvia. From oversized, misshapen, low-grade sweetpotatoes, they have made a high-value frozen product that rivals—and can exceed—the quality of top-grade fresh sweetpotatoes.

"Now, the biggest market for sweetpotatoes is fresh consumption," Walter says. "One reason for this is that processors have not been able to control textural properties that depend on the variety and how the sweetpotatoes are handled after harvest."

And most people prefer a baked sweetpotato, he says, which takes about an hour in a conventional oven.

At the ARS Food Science Research Unit in Raleigh, North Carolina, Walter and Truong ground up low-grade sweetpotatoes. To this they added two types of cellulose texturizing agents and a little sugar and froze the mixture in sausage casings. They later removed the casings and baked the sweetpotato rolls, unthawed, in a conventional oven at 400°F for 15 minutes.

The result: definite "down-home" taste and quality, in a fraction of the time.

A 30-member taste panel rated the new product equal to baked fresh sweetpotatoes in flavor and overall acceptability. They found no significant differences in color or texture.

Furthermore, "one of the additives that we used to maintain textural quality could actually increase the health value of the sweetpotatoes," Walter says. "Studies have shown that MHPC (methylhydroxypropylcellulose)—a compound that's widely used in the food industry in texture modifiers, thickeners, binders, and stabilizers—may lower blood cholesterol levels."

Although sweetpotato french fries have been served in restaurants for a few years, they haven't caught on, perhaps because they tend to be a little soggy rather than crisp.

Walter and Sylvia have increased firmness of french fried sweetpotatoes 100 percent with an alkaline-neutralization treatment.

They withdrew gases from sliced sweetpotato strips and replaced them with a dilute alkaline solution, in a process called vacuum-infusion. The strips were then blanched and again vacuum-infused with a weakly acidic solution to return the tissue to its normal acidity. They rinsed, froze, and then deep-fried the strips.

Taste panelists liked the taste and crunchy texture. There was no mention of off-flavor, but it was noted that there was very little of the characteristic sweet taste.

"This is a plus," Walter says. "It actually makes the sweetpotato more versatile. We can add various flavorings, depending on consumer preference."

He says these new procedures, which could open up a new market for growers, will work on all grades of sweetpotatoes. In 1993, North Carolina, Louisiana, and California produced most of the 1.2 billion-pound U.S. sweetpotato crop.—By **Doris Stanley,** ARS.

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Enlisting the Help of Soil-Searching Wasps

Jim Carpenter has been kneeling for several hours, digging in the soil on a 90-degree summer day in Georgia, sweat dripping, his back aching, when he realizes that there are some things insects and skunks can do better than he can.

Carpenter and his fellow Agricultural Research Service scientists come to this realization while scraping their trowels along the soil, trying to uncover 2-inch-deep tunnels from which corn earworm and fall armyworm pupae are waiting to emerge into adulthood.

He digs carefully, like an archaeologist who doesn't want to put a shovel blade through a piece of pottery. He's collecting the pupae so he can see if his wasps have already found them. A wasp cocoon in the tunnel or a dead, mummified pupa is a telltale sign that the wasps have done their job.

The three parasitic wasps he's recruited don't need a trowel to find the tunnels, which range from pencil-thick to AA battery-size. The wasps sense chemical aromas, called kairomones, from the silk that lines the tunnel walls and the cap that seals the top of the tunnel.

Once the wasps have detected the scent, they hover over the spot and vibrate their antennae, sending sound waves into the soil. Then they wait for the echo. Sound travels more slowly through solid soil than through the air inside the tunnels. Based on how long it takes for the sound to return, the wasps can tell if they've found their prey.

That the wasps are better at doing this than scientists comes as no surprise to entomologist Carpenter. He's just hoping they're good enough to make them prime biocontrol candidates. If so, they can help control the earworm, armyworm, and other Heliothis/Helicoverpa pests that cost farmers an estimated $2 billion a year in yield losses and chemical control costs.

It turns out that skunks are pretty good at finding the tunnels, too. Skunks have a keen sense of smell and relish the same pupae the wasps are looking for. Carpenter's not proposing skunks as a control strategy, but at the end of a long day of troweling he wouldn't mind putting their noses to work.

SCOTT BAUER

After releasing parasitic wasps in the cornfield, entomologist Jim Carpenter uses a trowel to expose tunnels in the soil that lead to corn earworm pupae. Samples of the pupae are then collected and checked for parasitism. (K5555-7)

"We've joked that maybe we ought to get some pet skunks, put them on a leash, and let them find the tunnels," he says. "Of course, we'd have to train them not to eat the pupae."

Carpenter believes that the future control of the earworm, armyworm, and pests like them lies not in the air but in the soil.

"It's critical to suppress the pests early in their life cycle—while they are pupae in the soil and before they emerge into mobile, reproductive adults," says Carpenter, who is based at the ARS Insect Biology and Population Management Research Laboratory in Tifton, Georgia. "Otherwise, populations explode. It becomes more difficult and expensive to control them once they lay their eggs and the hatched larvae begin devouring plants."

He says the pupal parasites would fit into an overall areawide management program by knocking down early-season pest populations. Other parasitic wasps could be used later to attack whatever eggs or larvae make it to the plants. The pupal parasites might also be useful in reducing overwintering populations.

Alternative forms of pest control have been getting more attention as the earworm, armyworm, and other crop pests develop resistance to insecticides. Carpenter and colleagues are evaluating three wasps in a 2-year field test in Georgia, Arkansas, Texas, and Oklahoma.

Two of the three wasps are native to the United States. *Diapetimorpha introita* attacks fall and beet armyworm pupae, while *Cryptus albitarsus* attacks the tobacco budworm. ARS entomologists Sam Pair, now at Lane, Oklahoma, and Harry Gross at Tifton discovered the two natives in Georgia—*D. introita* in 1981 and *C. albitarsus* in 1984.

Both wasps work like this: Once a female locates a tunnel under the soil, she sticks her ovipositor—up to one-half-inch long—into the soil and through the tunnel cap, depositing an egg inside. Within 36 hours, the egg hatches, and the larva crawls downward. The tiny wasp larva grabs hold of the pupa, pierces it, and begins sucking the fluid out of it, killing it within several days.

The third wasp, *Ichneumon promissorius*, is native to Australia and attacks 10 U.S. pest species—

Cross section of a tunnel with a corn earworm pupa. The *Diapetimorpha introita* wasp is preparing to lay an egg in the pupal tunnel. (K5557-9)

particularly corn earworm, tobacco budworm, and fall armyworm. Carpenter says *I. promissorius* is the only known parasitic wasp that attacks corn earworm pupae. Pair imported the wasp under quarantine in the late 1980's, and Carpenter observed it in the lab until the field studies began last year.

I. promissorius operates a bit differently than the two native U.S. wasps. When a female finds a pupal tunnel, she actually burrows into the soil, using her legs and head to dig through the cap and into the tunnel itself. Then she moves to the bottom of the tunnel, finds the pupa, and lays an egg directly into it. Within a day or two, the wasp egg hatches, and the larva begins to eat the pupa.

For wasps to be effective, Carpenter says, large numbers will have to be released—and at the right time, when the pupae are still in the soil. In field tests, the scientists have chosen areas where pest infestations are high—up to 10,000 pupae per acre. On a 40-acre site in the Rio Grande Valley of Texas last summer, the scientists released 2,000 female *I. promissorius* wasps to gauge their effectiveness.

"Based on preliminary data, they are finding and parasitizing the pupae," Carpenter says. "In Australia, up to 20 percent of the pupae recovered have been parasitized. We hope these wasps will provide similar results in the United States."

Artificial Diet for Mass-Rearing

One key factor in the future success of the wasps will be finding a way to mass-rear them. Carpenter is working with ARS chemist William Schlotzhauer at Athens and ARS entomologist Patrick Greany at Gainesville, Florida, on ways to rear the two native wasps.

In lab rearing, scientists induce the two native wasps to lay their eggs in the pupal tunnel. Then the researchers remove the eggs. "What we want to do is develop a substrate that the wasps will land on and lay eggs into," Carpenter says. "Then we can collect the eggs much more easily."

Greany is working on a 100-percent artificial diet for *D. introita*. The work is preliminary, however, and in lab studies so far only 35 percent of the newly hatched larvae develop into adults after feeding on the artificial diet. "We need to get about 70 to 90 percent of the larvae to fully develop before the diet can be used commercially," says Greany.

Meanwhile, Schlotzhauer is isolating and identifying the silk kairomones so they can be incorporated into the substrate to entice the wasps to lay eggs. "Each wasp responds to very specific kairomones, and a minor change can have a significant effect," he says. "The sensitivity of the wasps to these kairomones is phenomenal."

Carpenter adds, "The prospects are good for developing artificial diets, oviposition sites, and stimuli for mass-rearing these wasps. When we do that, our chance of using these wasps for areawide management will be greatly enhanced. It may be possible that farmers will be able to use them on a commercial basis one day."—By **Sean Adams,** ARS.

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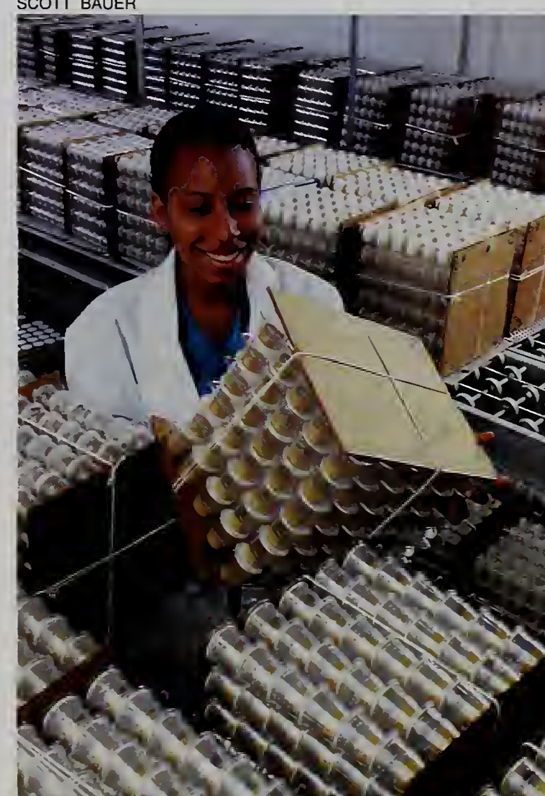

Research apprentice Sherri Day inspects development of corn earworm pupae that will be used to produce control parasites for release in the field. (K5554-2)

74555; phone (405) 889-7395, fax (405) 889-5783.

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William Schlotzhauer is at the USDA-ARS Richard B. Russell Research Center, P.O. Box 5677, Athens, GA 30613; phone (706) 546-3194, fax (706) 546-3454. ◆

Native Americans Fight Weeds To Keep Their Land

On the Crow Reservation near Pryor, Montana, landowner Phillip Beaumont examines Canada thistle in a 200-acre field that's also infested with bindweed and wild oats. (K5707-1)

Phil Beaumont owns 700 acres on the Crow Reservation in Pryor, Montana. Over the past 73 years, he's watched Canada thistle and bindweed take over 160 acres of prime winter wheat cropland. Land that formerly produced 60 bushels per acre now yields less than 20.

Warren Matte has a 1,000-acre ranch along the Milk River floodplain on the Fort Belknap Reservation near Dodson, Montana. Leafy spurge is his nemesis. Because of spurge, the Bureau of Indian Affairs (BIA) previously quarantined his land. He could not sell or move his hay because it could spread the weed.

Beaumont and Matte are just two of hundreds of Native Americans who are fighting to keep weedy invaders off their land. In Montana alone, nine noxious weeds infest almost 600,000 of the 5 million acres of Indian Trust lands.

Now scientists in the ARS Range Weeds and Cereals Research Unit in Bozeman and Sidney, Montana, are helping reservation land managers use biological control to stop the weeds on 14 reservations in Montana, North Dakota, Wyoming, and Idaho.

From Flea Beetles to Russian Rusts

Dan Spencer, a soil scientist and the BIA weed specialist at Fort Belknap, says the reservation is ideal for biocontrol. "The Matte land is sensitive to chemicals because of a high water table, and the landowners generally don't want chemical applications.

"Also, biocontrol insects and pathogens such as plant diseases and rusts are useful because they ignore property boundaries," Spencer says. "A common problem on the reservations is finding someone to take responsibility for a weed problem on a piece of land.

"When the weed problem started, there may have been only one owner. Today, the ownership of that land may include over 100 joint owners." Matte's land at Fort Belknap is divided among eight owners, all in the same family.

ARS also benefits from the cooperation with BIA, because agency scientists can field-test solutions to real-world weed problems.

In 1992, ARS scientists from Bozeman and Sidney released 1,800 flea beetles (*Aphthona flava, A. nigriscutis,* and *A. cyparissiae*) to try to curb one of the most troublesome weeds—leafy spurge—on three reservations. They also set up 30 test sites for leafy spurge control, some on reservations [See "Leafy Spurge Is Reunited With Old Enemy," *Agricultural Research*, April 1994, pp. 20-22].

About 70 percent of the beetles became established and are reproducing. But it will be a few years before

JACK DYKINGA

populations increase enough for their feeding to provide noticeable control of the spurge.

This summer, Spencer and ARS plant pathologist Tony Caesar took their weed problem back to the source—leafy spurge's Eurasian homeland—to look for solutions.

The weed was brought to the United States with European settlers earlier this century.

Caesar and Spencer took spurge plants from Fort Belknap to the Stavropol (Russia) Agricultural Research Institute and planted them next to Russian leafy spurge plants. The Russian plants were infected with rust species that are also native to the Stavropol area.

"The rust reduces the vigor of the Russian plants, and we are testing whether it will have an even greater effect on American plants. If American spurge has lost some of its natural resistance to the rusts, the pathogens could make good biocontrol agents," Caesar says.

The city of Stavropol is in the Caucasus, an area in Russia between the Black Sea and the Caspian Sea. The area has a climate similar to Montana, and Caesar and Spencer believe the rusts and other soilborne diseases that attack spurge would also thrive on the U.S. Northern Great Plains.

Caesar, who has been to Russia twice before, says the foreign research trips have given him valuable insight into U.S. weed problems. "You can't go over there and leave without being convinced that biological control is the answer. Spurge is not a problem over there because insects and diseases keep it in check," Caesar says.

As Caesar studies the pathogens, Spencer will study the soil samples they collected on their trip. "Around Stavropol, spurge grows only in fine loamy sands. But in the United States, it grows everywhere—including in sodium-affected soil," Spencer says.

Even as they look for new clues to weed control, ARS and BIA scientists are distributing the insects already tested and imported into the United States. Most of the reservations are in the early stages of implementing biocontrol, but some are starting to see results.

"Musk thistle is a lesser problem than it used to be, and they're almost ready to go completely to biocontrol—with no chemicals—for leafy spurge on the Wind River reservation in Wyoming," says Larry Beneker, the Billings Area Soil Conservationist for the BIA.

Bill West, acting refuge manager for the U.S. Fish and Wildlife Service at the National Bison Range in Montana, looks out for the welfare of grazing bison.

To achieve that goal, he's been getting biocontrol insects from

JACK DYKINGA

Bison wander across a weedy area of the National Bison Range on the Flathead Indian reservation in Montana. (K5680-1)

Weeds Imperil Bison Herd

Humans are not the only American natives whose welfare depends on weed control. A herd of 370 American bison searching for native prairie grasses to eat often find noxious weeds instead.

Bison were returned to Montana's Flathead Valley in the 1870's. "A Pend Oreille Indian named Samuel Walking Coyote got six calves to follow his horse home, and he started raising them," says Bill West.

West is acting refuge manager for the U.S. Fish and Wildlife Service at the National Bison Range, which is in the middle of the Flathead Indian Reservation. Over 200,000 people visit the bison each year at this refuge, one of three in the United States. The others are in Nebraska and Oklahoma.

ARS scientists are working with West to control 10 species of weeds on the 18,500-acre range. So far, ARS has released 15 insect species to fight 6 of the weeds.

According to West, the key to keeping the bison healthy is to maintain the native prairie of rough fescue, bluebunch wheatgrass, and Idaho fescue grasses. "We don't cut hay here—the bison roam where they want," he says. "We also have a responsibility to care for the grasslands that evolved here."

Bison herds were devastated during the settlement of the West. At their peak, there were 60 million animals; by 1882 as few as 100 free-roaming bison remained in the wilds of North America. Careful management of private herds has brought the species back to a current level of 130,000.—By **Kathryn Barry Stelljes,** ARS.

USDA scientists since 1948. Two species of *Chrysolina* beetles that have been very effective in California and the beetle *Agrilis hyperici* have had cyclical success in controlling St. Johnswort on the bison range. "It's very dramatic to go from 6,000 to 100 acres of the weed," West says.

The problem, he adds, is that the beetle population dies back before killing the plant. "The drier climate may cause cyclical control rather than the permanent reduction seen in California," he says. "About every 6th year, the beetles just flat chew the weed to the ground, but other years are horrible."

To help the beetles, ARS entomologist Norm Rees released the moth *Aplocera plagiata* 2 years ago. The moth eats the St. Johnswort leaves and prefers dry areas. "In Canada, this species has been very effective in those areas where the beetles have not," Rees says.

As for musk thistle control, West considers it to be a complete success at the National Bison Range. Rees and West have been using the weevil called *Rhinocyllus conicus* since the early 1970's. West estimates that thistle infestations have dropped from up to half the range—about 9,000 acres—to under 25.

"Sometimes the thistle shows up along roadsides, but we don't see musk thistle in our grasslands anymore," West says.

No one believes that the American Wild West will ever again be completely free of foreign plant species. But ARS, BIA, and Fish and Wildlife scientists believe that biological control—along with judicious chemical and mechanical methods—will prevent them from taking over.—By **Kathryn Barry Stelljes,** ARS.

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JACK DYKINGA

▶ **Bureau of Indian Affairs weed specialist Dan Spencer (left) discusses with Tracy King, vice chairman of the Fort Belknap Community Council, eradication of leafy spurge that has infested the property of Warren Matte. (K5710-1)**

▼ **Near White Sulphur Springs, Montana, in the midst of a leafy spurge infestation, plant pathologist Tony Caesar checks an area where the spurge has been killed by a coral fungus that attacks the roots. (K5713-1)**

JACK DYKINGA

Fungus and Nematode Pesta

New, Improved Recipes for Pest Control

Scientists at three Agricultural Research Service labs are closing in on commercial recipes for Pesta, a unique product concept for biocontrol alternatives to chemical pesticides.

Pesta is mainly wheat-flour dough, plus either fungi that kill weeds or nematodes that kill insects. Few such fungi or nematode products now on the market come in dry, flowable granules like Pesta. But recent lab and field results from 5 years of ARS research make Pesta more attractive as a commercial option.

"We anticipate that nematode Pesta granules, with a room-temperature shelf life of more than 6 months, could be an effective control for western corn rootworms, Colorado potato beetles, and perhaps other insect pests," says nematologist Bill Nickle. He is at the Nematology Laboratory in Beltsville, Maryland.

In Stoneville, Mississippi, plant pathologist Doug Boyette has 4 years of field results at the Weed Science Laboratory. They show that Pesta with fungus suppresses hemp sesbania, one of the worst weeds of Southern rice, cotton, and soybeans.

Chemist Bill Connick at the Southern Regional Research Center in New Orleans is optimistic. But, he cautions, "Pesta still needs a mass-production process to realize its commercial potential."

Pesta: The Original Recipe

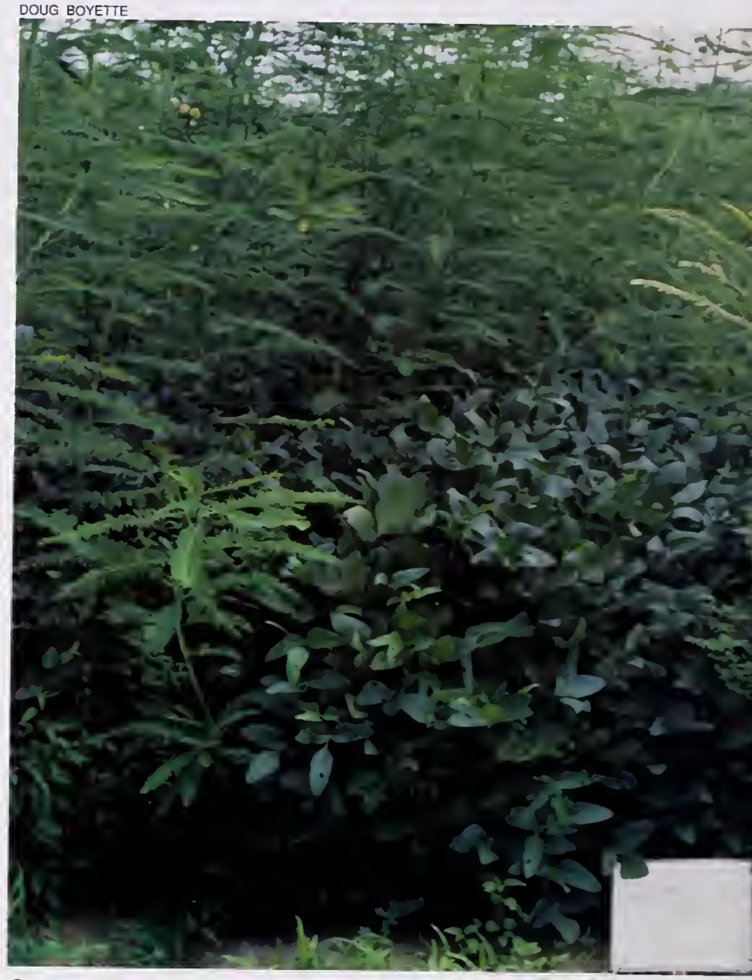
When Connick and Boyette began collaborating in 1989, they envisioned dough-based granules as a fungus carrier. Dough—made from flour and water—was cheap, cohesive, and biodegradable. Gluten and carbohydrates in the flour would supply nutrients for fungi after the granules were applied in a crop field.

But the researchers puzzled over how to turn globs of dough into dry, free-flowing, storable granules. "I wondered if food technology held an answer," Connick says, but he rejected breakfast cereal processes. Cereal granules get cooked, and cooking would kill the fungi.

Some people take their work home; Connick took his to the supermarket. "One day in the pasta aisle," he recalls, "I picked up a pack of spaghetti and realized pasta dough can be prepared, rolled out, and dried at room temperature."

He soon found that kaolin clay, an inexpensive filler, could replace up to about 30 percent of the flour. But to improve the early Pesta product, he needed a technician—improbably, one familiar with both doughmaking and fungi.

DOUG BOYETTE



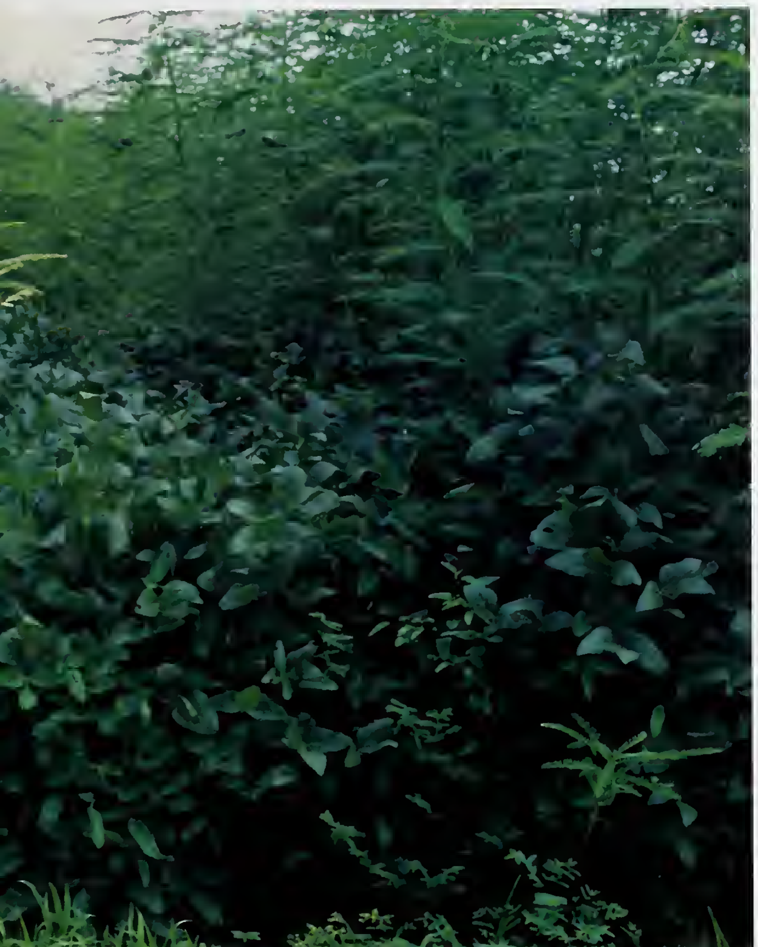
Over 90 percent control of hemp sesbania was achieved in this four-row soybean plot, the two center rows of which were treated with Pesta containing *Colletotrichum truncatum* fungus.

Then he found Kelley Williams, with an undergraduate degree in food science—and work-study experience with weed-killing fungi. Connick and Williams experimented with making pasta dough from durum wheat flour extruded through a small pasta machine.

"We had a lot of failures," Connick says. "Although most fungi survived well, we got very good at accidentally killing nematodes." But they refined the process through more than 100 different recipes, to eventually make a fungus Pesta

storable at room temperature for over a year and a nematode Pesta storable for 6 months.

"Pesta sheets containing the living biocontrol organisms dry on racks for about a day," he says. "We break them up and sieve the fragments through screens to get granules 1 to 2 millimeters (about 1/25th to 1/12th of an inch) in diameter." The granules then go into storage and testing.



Doug Boyette notes that chemical herbicides subdue hemp sesbania in rice and soybeans, but they can damage rice after midseason. Plus, accidental aerial drift of herbicide may harm nearby cotton.

Last summer, as in the 3 previous years, his *Colletotrichum truncatum* fungus Pesta killed more than 90 percent of hemp sesbania weeds—planted as seed amid outdoor soybean plots. Bean yields in Pesta-protected rows equaled those in rows sprayed with herbicide.

The fungi quickly get to work, blossoming on a granule once it's moistened by dew, rain, or water in the soil. After fungal enzymes open an invasion path into sesbania roots, stems, or leaves, the fungus spreads between plant cells, engulfing the weed's tissue.

Could Pesta one day be used to deploy multiple fungi species, since farmers likely prefer a product to suppress most, if not all, their problem weeds?

"That has potential, but it's very complicated," Boyette says. "Not all weed pathogens get along together, and weeds emerge at different times or are vulnerable only at some growth stages. In any event, hemp sesbania alone is sometimes serious enough that there may be a niche market for *C. truncatum*."

Boyette thinks Pesta's main technology hurdle is that the granules have to be very close to the weed—within a couple of millimeters. His field applications range upward from 75 pounds per acre of granules, with less than 1 percent of this the active ingredient (fungus).

But he's planning a new strategy along with Connick and microbiologist Mark Jackson at ARS' National Center for Agricultural Utilization Research in Peoria, Illinois. Instead of putting the sporal stage of *C. truncatum* in Pesta, they are testing whether microsclerotia—the overwintering, inactive stage—can boost the organism's performance and allow lower application rates.

DAVID NANCE

Plant pathologist Doug Boyette shows the results of applying Pesta granules to the greenhouse-grown weeds on left. (K5724-1)

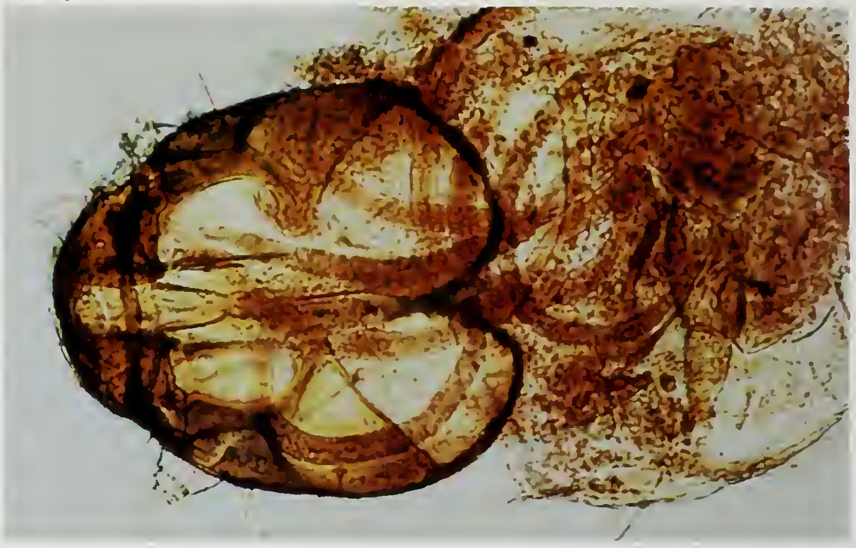
Delivering a Poison Pill to Insect Pests

Thirty-five years ago, the bacteria that team with nematodes to kill insects were first discovered by ARS nematologist Sam Dutky, now retired.

Today in this country, nine commercial products contain nematodes for killing a variety of insects. The products can be effective when fresh, and the nematodes come "packed in material ranging from tea bags to vermiculite to beach sand," says Bill Nickle.

Steinernema carpocapsae, the main nematode in Nickle's studies, delivers *Xenorhabdus nematophilus* bacteria as its

BILL NICKLE



Bill Nickle smiles when colleagues at meetings ask about his "high-tech method" for staining insects to reveal—without tedious dissection—if, where, and how many nematodes infect them. "An insect's fat makes its body opaque," he explains. "You can't see any nematodes." To make an insect translucent, he dissolves its fat and stains any nematodes inside it with Grenacher's borax carmine stain. Nickle says it was invented in 1879 and consists of borax, carmine, and ethyl alcohol. It makes possible light micrographs such as this one of a western corn rootworm larva parasitized by stringlike *Steinernema carpocapsae* nematodes.

"poison pills" after it invades an insect larva. "Only one nematode needs to get in," he says.

After penetrating the gastrointestinal tract, it "seeds" the bacteria, which multiply and kill the insect. Nematodes feast on the bacteria and reproduce. Their offspring depart to lurk in ambush for new victims.

In recent greenhouse tests, Nickle placed Pesta granules containing *S. carpocapsae* nematodes in moist soil, along with larvae of western corn rootworm and prepupae of Colorado potato beetle—two of American agriculture's most notorious pests. More than 90 percent were dead within 3 days.

The rootworm, corn growers' No. 1 insect enemy, costs over $1 billion annually in yield loss and control measures. Larvae hatch from eggs on or in the soil and chew the stalks, frequently toppling tender seedlings.

Colorado potato beetles, which devour foliage on potatoes, tomatoes, and eggplants, resist most insecticides. Some chemical controls are suspected groundwater contaminants.

BRUCE FRITZ

Chemist William Connick, Jr., cranks Pesta containing nematodes out of a pasta machine, while biological technician Kelly Williams prepares to count the live nematodes released from a water-soaked Pesta sample after storage. (K5692-1)

For the Pesta-makers, nematodes proved fussier than fungi. With one of the first nematode Pesta formulas—for refrigerated storage, which should have helped matters—"all the beneficial parasites were dead after 6 weeks," Nickle says.

An early room-temperature Pesta kept them alive only 8 weeks. But the latest recipe approaches commercial feasibility—26 weeks.

Nematode Pesta now consists of durum or bread wheat flour, kaolin and bentonite clays, peat moss, water, nematodes, and a compound that protects nematodes from fungi that might prey on them in storage. About 194 million nematodes are in a pound of the dry granules.

Gluten—the sticky protein in flour—makes the dough cohesive and retains moisture in the granules. It also immobilizes nematodes "so they don't wiggle out of the pancake" while it dries, Nickle says. He suggested the peat because it's often part of a nematode's natural home.

"We also think the peat helps wick water into the granules, so they fall apart easier and help nematodes get out," adds Connick. "As for the bentonite, it holds much more moisture than kaolin. By replacing 4 percent of the kaolin with bentonite, we can incorporate 40 percent more nematode slurry and still have a workable, cohesive dough."

Nickle plans the first outdoor tests of nematode Pesta granules in 1995. The granules would target rootworms and late-stage beetle larvae and pupae in the soil. But young beetle larvae fattening up on leaves would escape. So Nickle and Beltsville colleague Martin Shapiro are developing and testing a foliar spray with compounds that shield nematodes from ultraviolet rays and from drying—and dying—on the vine.

Meanwhile, Connick is attempting to extend the scope of Pesta granule applications by incorporating fungi that kill insects.—By **Jim De Quattro,** ARS.

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William J. Connick, Jr., and Kelley S. Williams are at the USDA-ARS Environmental Technology Research Unit, Southern Regional Research Center, P.O. Box 19687, New Orleans, LA 70179; phone (504) 286-4527/4526, fax (504) 286-4367.

C. Douglas Boyette is at the USDA-ARS Southern Weed Science Laboratory, P.O. Box 350, Stoneville, MS 38776; phone (601) 686-5217, fax (601) 686-5422. ◆

A Dual Citrus Threat

More severe strains of tristeza—plus the brown citrus aphid—could mean trouble for growers.

SCOTT BAUER

Plant pathologist Tina Behe inspects the damage of tristeza isolate B6 on Duncan grapefruit. This isolate was one found in California and is severe, causing stem pitting, vein clearing, and extreme stunting. (K5648-9)

To the naked eye, it looks just like any other dark-colored aphid found on plants. And like other citrus aphids, it feeds on tender, new citrus growth.

But the brown citrus aphid is different. Not only does it damage citrus directly through feeding, but it can also carry a concealed weapon—severe strains of the deadly citrus tristeza virus (CTV).

"Tristeza is one of the most serious and costly diseases facing U.S. citrus growers today," says Edwin L. Civerolo, ARS national program leader for horticulture in Beltsville, Maryland. "If more severe strains of the virus are introduced into the United States and become widespread, the citrus industry could lose more than $1 billion over the next few years."

Although the brown citrus aphid, *Toxoptera citricida,* has not yet arrived in the continental United States, it has been discovered in eastern Cuba and could soon be only 90 miles from Florida.

"We assume that this aphid will eventually show up in our citrus groves," Civerolo says, "so ARS has stepped up research on both tristeza and its carrier in recent years. We have an intensive, multi-location effort under way."

The pest and the disease it spreads could pose a major threat to Florida's $8 billion citrus industry and later to citrus in California, Texas, and Arizona. The 92 million citrus trees in Florida produce 81 percent of the nation's citrus fruits.

Civerolo coordinates the broad range of research efforts directed against tristeza and the new pest with USDA's Animal and Plant Health Inspection Service, the citrus industry, state regulatory agencies, and Florida, California, and Texas university scientists.

Brown citrus aphids suck sap from citrus, directly weakening tree vigor. The aphid transmits citrus tristeza virus when it inserts its mouthparts into veins of healthy leaves after feeding on virus-infected trees.

"We have a quarantined collection of citrus viruses, including severe strains of tristeza, gathered from all over the world and maintained here at Beltsville," Civerolo says.

These isolates, plus colonies of the brown citrus aphid kept at the Foreign Disease-Weed Science Research Laboratory—an ARS quarantine facility in Frederick, Maryland—are a unique resource. They enable scientists to study how efficiently tristeza strains are transmitted, without jeopardizing commercial groves.

CTV Strains Are Already Here

Mild strains and decline strains of the tristeza virus have become widespread in Florida citrus groves since 1950, unlike the more serious stem-pitting strains so readily transmitted by the brown citrus aphid.

Quick-decline strains can rapidly kill trees on sour orange rootstock but do not affect trees on other types of rootstocks. Stem pitting reduces yield in trees on all rootstocks.

Tristeza is spread by grafting and by three aphid species: the melon (also called the cotton aphid), the spirea, and the black citrus.

All sweet orange, grapefruit, and mandarin trees grown on sour orange rootstock are susceptible to quick decline. Between 18 and 20 million trees are growing on this rootstock in Florida, with 15 million more in Texas, Arizona, and California.

"We don't know the full economic impact that this new aphid may have on Florida citrus, but damage to trees on sour orange alone could exceed $500 million over the next 20 years,"

SCOTT BAUER

Brown citrus aphids shown about six times actual size. (K5646-2)

predicts Richard Gaskalla, who is director of the Division of Plant Industry in the Florida Department of Agriculture and Consumer Services.

Gaskalla says that grapefruit and sweet orange industries may well be affected, regardless of the rootstocks involved, if severe stem-pitting strains of citrus tristeza virus appear.

An eradication program has limited the spread of tristeza in the Central Valley of California, but current efforts may not be sufficient.

"*Aphis gossypii,* or the melon aphid, is currently the most efficient vector in Florida," says Raymond K. Yokomi, an entomologist in the ARS Subtropical Insects Research Laboratory in Orlando. "But the brown citrus aphid is 6 to 20 times more efficient, increasing the potential magnitude of the problem."

Citrus Groves in Maryland?

These trees have been planted more than 800 miles north of the East Coast citrus belt.

Tina Behe, an assistant plant pathologist with the University of Florida, maintains this quarantine "citrus grove" in greenhouses at the Agricultural Research Center in Beltsville, Maryland.

Healthy plants are shipped from Orlando and then infected with many different strains of citrus tristeza virus (CTV) including some from India, Indonesia, Costa Rica, China, Brazil, and Japan.

Kept in the controlled environment of greenhouses, the 300 virus-infected plants are part of a project funded by ARS through a cooperative research agreement with the University of Florida.

ARS and university researchers from Florida and California are comparing CTV strains from different countries. They're also looking for mild strains that can "cross protect" U.S. citrus from more severe strains of the pathogen. Cross protection in plants is akin to vaccination in animals.

"Many of the foreign strains are so much more severe than the U.S. strains used for comparison," Behe says. "Even mild strains from other countries cause strong symptoms."

"We also use the collection for research on how the brown citrus aphid transmits the virus," Behe explains. She provides virus-infected citrus to the ARS quarantine facility in Frederick, Maryland, where the brown citrus aphid colonies are maintained.—By **Doris Stanley**, ARS.

Although there is no way as yet to stop the virus once it attacks a tree, scientists at the U.S. Horticultural Research Laboratory in Orlando are working on better ways to detect infection by severe strains and to thwart the brown citrus aphid when it arrives.

Plant pathologist Steve Garnsey and former ARS scientist Thomas A. Permar developed and patented, in 1992, monoclonal antibodies that differentiate between severe and mild CTV strains. Now used commercially in Florida to verify that nursery trees are free of severe citrus tristeza virus, the antibodies are used worldwide in research.

"We're also working on a genome map of the virus—the longest RNA plant virus known—to help us understand how it causes disease," Garnsey explains. "Once we've identified the virus genes and studied their functions, we can think about genetically altering citrus to resist CTV infection. This will be a long, complicated process."

Sequencing of one CTV strain is just complete, after 5 years of intensive research, he says. Funded by ARS, this work was collaborative with scientists from the universities of Florida and California. The CTV coat protein gene has already been identified and inserted experimentally into several citrus cultivars by University of Florida scientists.

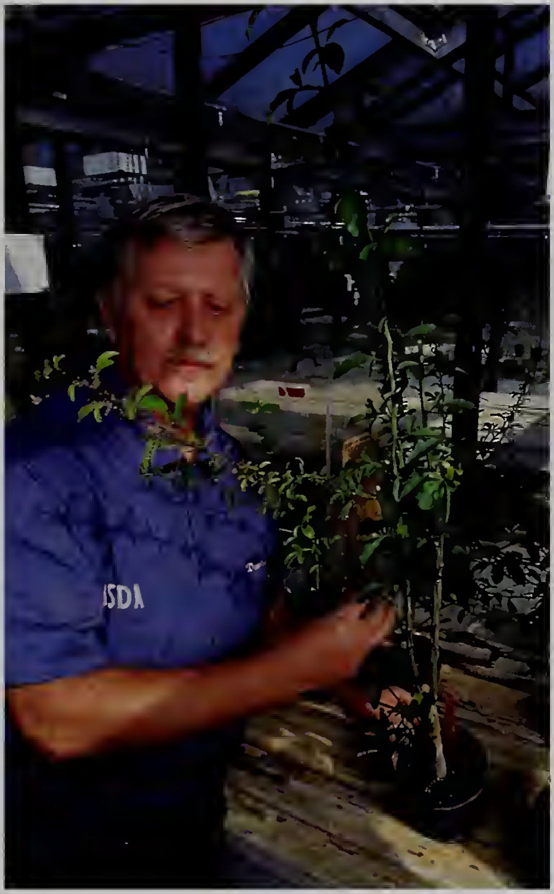
At Orlando, ARS plant breeder Herb C. Barrett has developed and released a breeding line of citrus that resists the virus. Called US119, this germplasm is available to develop new, CTV-resistant varieties.

Garnsey and colleagues have also been infecting healthy citrus with mild forms of the virus to protect against the attack of more severe, damaging strains.

The threat of the brown citrus aphid raises new concerns about the number of CTV strains for which protection will be needed. Lab tests have shown that where protection fails, trees can carry both mild and severe strains at the same time.

Plant pathologist Tim R. Gottwald and Garnsey maintain citrus test plots in the Caribbean to determine how the brown citrus aphid spread CTV there.

SCOTT BAUER



At the Foreign Disease-Weed Science Research Laboratory in Frederick, Maryland, plant pathologist Vernon Damsteegt checks on colonies of brown citrus aphids collected in Hawaii. (K5649-4)

"We're also monitoring the movement of the virus in Costa Rica, Spain, and Taiwan," Gottwald says. "This helps us develop models to predict how tristeza will move, if the brown citrus aphid becomes established here."

Yokomi is testing possible biological controls of the pest. He has explored Malaysia, Taiwan, and China—where severe strains of the virus are rampant and the aphid is present—for natural enemies.

"We found several parasitic wasps attacking the brown citrus aphid in Asia, Venezuela, and Puerto Rico," Yokomi says. One of these is now at the Florida Department of Agriculture and Consumer Services quarantine facility at Gainesville.

"In greenhouse tests, this parasite from China readily attacked the spirea aphid, the most common citrus aphid in the United States," he reports.

Yokomi and colleagues have also found a previously unrecognized parasite of aphids in Florida, a gall midge that parasitizes up to 50 percent of spirea aphid populations in dooryard citrus trees and ornamentals.

"If the brown citrus aphid becomes established in the United States, we're hoping that the exotic parasites, coupled with the gall midge and other indigenous natural enemies and pathogens, could lower aphid numbers to tolerable levels," he says. "This, integrated with cross protection, limited amounts of pesticides, and insect pathogens, could be an important defense against the new pest."—**By Doris Stanley**, ARS.

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